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EXECUTIVE SUMMARY

MEASUREMENT OF HTO PERMEATION RATES THROUGH VARIOUS CANDIDATE DISPOSABLE PLASTIC SUIT MATERIALS

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Disposable plastic suits used presently at Ontario Hydro nuclear facilities are made of polyvinyl chloride (PVC). Because of the high chlorine content of PVC, incineration as a disposal option is not desirable. Safety Services Department has a program to evaluate various materials that could replace PVC in disposable plastic suits which would not only meet or exceed the tritium protection capability of PVC but be compatible with incineration. Protection factor measurements determine the actual degree of protection that a plastic suit provides to a human subject working in a simulated work environment. As a first step in identifying candidate materials for protection factor measurements simple permeation tests using tritiated water were carried out.

The materials can be ranked both in terms of the permeation rate and also in terms of the permeability constant of the material. This latter ranking is a characteristic property of the single materials and is independent of thickness. Ranking by permeation rate on the other hand, as long as the tritium source term is constant, provides an insight into the relative protection factors that can be expected based on permeation characteristics afforded by plastic suits fabricated from these materials and is perhaps the more relevant.

The results show that Saranex has the lowest permeability coefficient of the materials tested by virtue of its low water solubility and therefore should afford the best protection factor as a plastic suit material used in tritium service.

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MEASUREMENT OF HTO PERMEATION RATES THROUGH VARIOUS CANDIDATE DISPOSABLE PLASTIC SUIT MATERIALS

J.P. Krasznai and B.D. Aucoin

Safety Services Department is invertigating the protection factor for tritiated water exposure afforded by various disposable plastic suit materials. Protection factor determinations are expensive and therefore as a guide in assessing the relative permeation behaviour of the candidate materials we have determined the water vapour permeation rate, the permeability coefficient of the materials and the tritiated water diffusivity in these materials. The results of these tests indicate that the composite material Saranex based on its permeation behaviour will provide the best tritium protection factor.

1.0 INTRODUCTION

Disposable plastic suits used presently at Ontario Hydro nuclear facilities are made of polyvinyl chloride (PVC). Because of its high chlorine content incineration as a disposal option is not desirable. Safety Services Department has a program to evaluate various materials that could replace PVC in disposable plastic suits which would not only meet or exceed the tritium protection capability of PVC but be compatible with incineration. Protection factor measurements determine the actual degree of protection that a plastic suit provides to a human subject working in a simulated work environment. As a first step in identifying candidate materials for protection factor measurements simple permeation tests using tritiated water were carried out. The results of these tests are reported here.

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2.0 EXPERIMENTAL

The permeation cell and the flowsheet schematic have been described previously/1/. The tests described in this report were carried out with tritiated water in contact with the membrane and a dry nitrogen sweep gas (50 mL/min) flowing over the downstream side of the membrane. This arrangement provides the highest concentration gradient across the membrane and in previous work was shown to increase the rate of permeation by an order of magnitude/2/.

Heavy water with a tritium activity of 9.2 mCi/g water was used in all of the tests with the exception of the composite materials which were expected to have very low permeation rates. Previous testing on the 4 mil thick Saranex material indicated that tritiated water permeation is very low and for the thicker material would be too low to determine a permeation rate reliably. Consequently we used heavy water with higher activity (20 mCi/g) for the runs with Saranex and Respirex. No attempt was made to control the temperature during the tests but it was reasonably constant at $23.0 \pm 0.5^{\circ}C$.

When the cells were assembled with the material covering the water it was impossible to avoid trapping a small air bubble under the material to be tested. The size of this bubble was measured and its surface area subtracted from the area of the membrane in the calculations of the permeability constant of the material. Strictly this is not valid because it assumes that no tritium permeates from the vapour volume of the bubble. Given the large variations expected between the materials, this factor is not expected to give rise to a significant error.

Previously/1/ we determined the instantaneous tritiated water vapour permeation rate by using a disposable plastic syringe to remove a 10 mL volume of the sweep gas every 15 minutes via the sampling septum and bubbling the gas through liquid scintillation cocktail. However integration of the individual septum samples agreed quite well with bubbler data in the case where tritium permeation rate was relatively high but the agreement was poor when the permeation rate was low. We attributed this discrepancy to adsorption of tritiated water to the walls of the plastic syringe effectively reducing the quantity bubbled through the scintillation cocktail. It has been pointed out/3/ that reliable data can be obtained using this method if glass syringes are used. In this work we modified the bubblers to enable them to be sampled without having to remove the bubbler head. The sampling procedure involved removing a 1mL sample of glycol solution from each bubbler every 15 minutes for the duration of the run. Each material (Table 1) was tested in duplicate to determine the reproducability of the measurements.

TABLE 1

MATERIALS TESTED

Material	Nominal Thickness(mil)	Weight/Area g/m^2
NSP-PVC-LC	5	251.9
NSP-PVC-LC	7	344.5
NSP-PVC-LC	12	535.2
DP-PVC (YELLOW)	6	220.5
DP-VINYL (AQUA)	12	525.1
NSP POLYETHYLENE	1.5	52.4
NSP POLYETHYLENE	3	95.3
RACAL PTFE	5	276.8
SARANEX (CLEAR)	6	275.4
SARANEX (CREAM)	7	235.1
RESPIREX	19	700.6

3.0 RESULTS AND DISCUSSION

Figure 1 to 6 show the relative tritiated water permeation behaviour of the materials. Permeation rate is directly proportional to the upstream tritium concentration. Consequently when comparing the relative behaviour of the materials the fact must be considered that the upstream tritium concentration was a factor of two higher in the case of the composite materials, Saranex and Respirex, than for the single component tests. The ranking of the materials in terms of the permeation rate is given in Table 2.

TABLE 2

RANKING OF DISPOSABLE PLASTIC SUIT MATERIALS

Rank	Material	Thickness (mils)
1	Saranex(Cream)	7
2	Saranex(Clear)	6
2	Racal-PTFE	5
3	Respirex	19
4	NSP-PE(Clear)	1.5
5	NSP-PE(White)	3
6	NSP-PVC	12
7	NSP-PVC	7
7	DP-PVC	6
7	DP-VINYL	12
8	NSP-PVC	5

The composite materials Saranex and Racal Teflon are the best of the materials tested followed by Respirex fire fighting suit material. As the figures show, the permeation rate of the PVC materials decreases as expected with increasing thickness.

Equation (1), derived in Appendix 1, relates the rate of permeation of tritiated water expressed in Ci/s to the permeability coefficient of the various materials expressed in conventional units $\frac{cm^3}{cmHg.cm^{-1}} \frac{(STP).cm^{-2}.s^{-1}}{}$.

$$R_{DTO}(Ci/s) = \frac{6.25 \times 10^{-4}}{1.295} \cdot \frac{a_o}{V} . K . P^{(s)}_{D2O} \cdot \frac{A}{l} \quad \text{——————(1)——}$$

where:

R_{DTO} is the rate of permeation of DTO vapour, Ci s^{-1}

K is the permeability coefficient of the material, $\frac{cm^3(STP).cm^{-2}.s^{-1}}{cmHg.cm^{-1}}$

a_o is the total tritium activity in Curies on the upstream side of the membrane.

$P^{(s)}_{D2O}$ is the saturation vapour pressure of D_2O at a given temperature, cmHg.

V is the volume (cm^3) of D_2O in contact with the upstream side of membrane.

A is the surface area of material in contact with D_2O, cm^2.

l is the thickness of material, cm.

Table 3 summarizes the permeation data calculated from equation 1 for the various materials. The column showing the permeation rate data was calculated from the gradient of the straight line in Figures 1 to 6 indicative of steady state permeation. The data from duplicate runs tabulated in Appendix 2 was averaged and the uncertainty represents the deviation of the individual runs from the average.

TABLE 3

PERMEABILITY COEFFICIENTS OF PLASTIC SUIT MATERIALS

MATERIAL	l (cm)	TEMP. (°C)	P(D2O) (cmHg)	R(DTO) (Ci/s) 10^{10}	K $\frac{cm^3(STP).cm^{-2}.s^{-1}}{cmHg.cm^{-1}}$ 10^{8}
NSP-PVC-LC(5)	0.015	23.0	1.8264	4.58±1.09	13.0±3.1
NSP-PVC-LC(7)	0.018	23.1	1.8382	3.90±0.62	13.4±2.1
NSP-PVC-LC(12)	0.032	23.4	1.8735	3.17±0.60	18.7±3.5
DP-PVC(6)	0.018	23.5	1.8852	5.05±1.51	16.7±5.0
DP-VINYL(12)	0.054	23.0	1.8264	3.73±0.37	35.2±3.8
NSP-PE(1.5)	0.005	22.8	1.8029	1.57±0.11	1.50±0.10
NSP-PE(3)	0.009	22.4	1.7558	2.90±0.38	4.93±0.67
RACAL-PTFE(5)	0.012	23.8	1.9205	0.27±0.02	0.58±0.04
SARANEX(CLEAR 6)	0.017	23.2	1.8499	0.28±0.02	0.026±0.002
SARANEX(CREAM 7)	0.020	22.6	1.7793	0.22±0.02	0.023±0.002
RESPIREX(19)	0.049	23.5	1.8852	0.58±0.00	5.04±0.02

The Saranex material, a co-extruded polymer manufactured by the Dow Chemical Company is a composite consisting of chlorinated polyethylene (CPE), ethylene vinyl acetate (EVA), Saran (polyvinylidene chloride) and ethylene vinyl acetate. Of the materials tested it is the best tritium barrier having a permeability constant almost three orders of magnitude lower than PVC. The value of the permeability constant for the PVC materials tested here ranged from a low of 1×10^{-7} to a high of 2.2×10^{-7} $cm^3(STP).cm.cm^{-2}.s^{-1}.cmHg^{-1}$. In these measurements we found no significant difference between the PVC material from the German manufacturer NSP and the Delta Protection PVC. By way of comparison the value of the 25°C permeability constant for plasticized PVC from the literature/4/ was 2×10^{-7} cm3(STP).cm.cm-2.s-1.cmHg-1.

The factor of three difference in the permeability coefficient of the polyethylene materials was unexpected. The two materials look very different and consequently they were both examined by Fourier Transform Infra Red Spectroscopy in an attempt to identify the materials. The spectra are quite different and the 3mil material identified as NSP-PE(white) has a strong band at 1725 cm^{-1} which is characteristic of the presence of a -C=O bond indicating oxidation of the material. This would have significant impact on the water permeability characteristics of the material and is consistent with our observations.

The Respirex material is a composite of Viton (hexafluoropropylene/ vinylidene fluoride copolymer) and butyl rubber (isobutylene/isoprene copolymer). Because of its high specific weight the determination of the permeability coefficient was expected to take longer than the previous materials. Consequently, we did not take samples for tritium determination as frequently as in the previous tests but allowed the test to run much longer to permit steady state permeation to be achieved. This was achieved

about 100 hours into the test which was carried out with the red portion of the material in contact with the tritiated heavy water. The permeability coefficient of this material towards water was similar to polyethylene.

The diffusivity of tritiated water in the various materials can also be determined from the graphs using the expression(4)

$$D = \frac{l^2}{6L} \qquad \text{——————(2)——————}$$

where:

D is the diffusivity of tritiated water,

l is the material thickness (cm)

L is the time lag which is the intercept of the straight line extrapolated to the time axis.

Table 4 summarizes the diffusivity data for the materials.

TABLE 4

DIFFUSIVITY OF TRITIATED WATER IN PLASTIC SUIT MATERIALS

MATERIAL	THICKNESS l (cm)	LAG TIME (s)	DIFFUSIVITY $(cm^2/s) \times 10^9$
NSP-PVC-LC(5)	0.015	9780	3.83
NSP-PVC-LC(7)	0.018	8520	6.34
NSP-PVC-LC(12)	0.032	13020	13.11
DP-PVC(6)	0.018	8520	6.34
DP-VINYL(12)	0.054	10886	44.64
NSP-PE(1.5)	0.005	7200	0.58
NSP-PE(3)	0.009	6540	2.06
RACAL-PTFE(5)	0.012	5400	4.44
SARANEX(CLEAR 6)	0.017	4901	13.60
SARANEX(CREAM 7)	0.020	5408	12.33
RESPIREX(19)	0.049	5684	70.40

The permeability coefficient of water in a material is defined as the product of the diffusivity (resistance to movement) and the solubility of water in the material. In view of the relatively large diffusivity of water in Saranex (Table 4) it would appear that it is the very low solubility of water in Saranex that is responsible for its very low permeability.

4.0 CONCLUSIONS

The permeation rate of heavy water and the permeability coefficients of a number of candidate disposable plastic suit materials have been determined. The materials can be ranked in terms of the permeation rate (Table 2) and

also in terms of the permeability constant of the material. This latter ranking is a characteristic property of the single materials and is independent of thickness. Ranking by permeation rate on the other hand, as long as the tritium source term is constant, provides an insight into the relative protection factors afforded by plastic suits fabricated from these materials and is perhaps the more relevant.

The results show that Saranex has the lowest permeability coefficient of the materials tested by virtue of its low water solubility and therefore should afford the best protection factor as a plastic suit material used in tritium service.

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2. Zeya, M., "Permeabilities of Protective Suit Materials To Tritiated Water," OHRD Report No. 88-193-K, April 20, 1989.

3. Stephenson, J., Private Communication. March, 1990.

4. Crank, J. and Park, G.S., "Diffusion in Polymers," Academic Press 1968.

APPENDIX 1

Calculation of the Permeability Coefficients for the Materials Tested

If liquid water is in contact with a material surface, the total rate of permeation is given by:

$$R_{D2O} = K.P^{(s)}_{D2O}.\frac{A}{l} \qquad \text{------(1)-----}$$

R_{D2O} is the rate of permeation of D_2O vapour, $cm^3(STP)\ s^{-1}$

K is the permeability coefficient of the material, $\frac{cm^3(STP).cm^{-2}.s^{-1}}{cmHg.cm^{-1}}$

$P^{(s)}_{D2O}$ is the saturation vapour pressure of D_2O at a given temperature, cmHg

A is the surface area of material in contact with D_2O, cm^2

l is the thickness of material, cm

If the D_2O contains a certain mole fraction, f, of tritiated heavy water DTO, then,

$$R_{DTO} = f.K.P^{(s)}_{D2O}.\frac{A}{l} \qquad \text{------(2)-----}$$

where f is $\frac{\text{number of moles of DTO}}{\text{number of moles of } D_2O}$

In a volume V (cm^3) of D_2O in contact with material, the number of moles of $D_2O = \frac{1.1V}{20.03} = 0.055V$ moles

1 mole of DTO contains 6.023×10^{23} radioactive molecules

$$\text{Activity (Ci) of 1 mole DTO} = \frac{6.023\times10^{23}}{3.7\times10^{10}\ \text{dps/Ci}} \times \frac{0.693}{t_{1/2}}$$

$$= 2.9 \times 10^4\ \text{Ci/mole}$$

where $t_{1/2}$ is the half life of tritium = 3.88×10^8 s

$$\text{Number of moles of DTO in V } (cm^3)\ D_2O = a(Ci/cm^3).V(cm^3).\frac{\text{mole}}{2.9\times10^4 Ci}$$

where a is the concentration of DTO in Ci/cm^3 and a.V is the total tritium activity (a_o) on the upstream side of membrane.

Therefore $f = \frac{a_o}{2.9\times10^4} \cdot \frac{1}{0.055V}$

$= 6.25\times10^{-4} \frac{a_o}{V}$

Substituting for f into equation 2

$$R_{DTO}(cm^3/s) = 6.25\times10^{-4} \cdot \frac{a_o}{V} \cdot K \cdot P^{(s)}_{D2O} \cdot \frac{A}{l} \quad \text{-------(3)------}$$

1 mole DTO at STP (0^oC and 760 mmHg) occupies 22.4×10^3 cm^3

2.91×10^4 Ci at STP occupies 22.4×10^3 cm^3

1 cm^3 DTO vapour at STP contains 1.295 Ci

Expressing equation 3 in terms of the measured quantity for R_{DTO} (Ci/s)

$$R_{DTO}(Ci/s) = \frac{6.25\times10^{-4}}{1.295} \cdot \frac{a_o}{V} \cdot K \cdot P^{(s)}_{D2O} \cdot \frac{A}{l} \quad \text{-------(4)------}$$

A graph of the total DTO permeated through each material as a function of time should yield a straight line whose gradient is R_{DTO}. The permeability constant K can then be calculated.

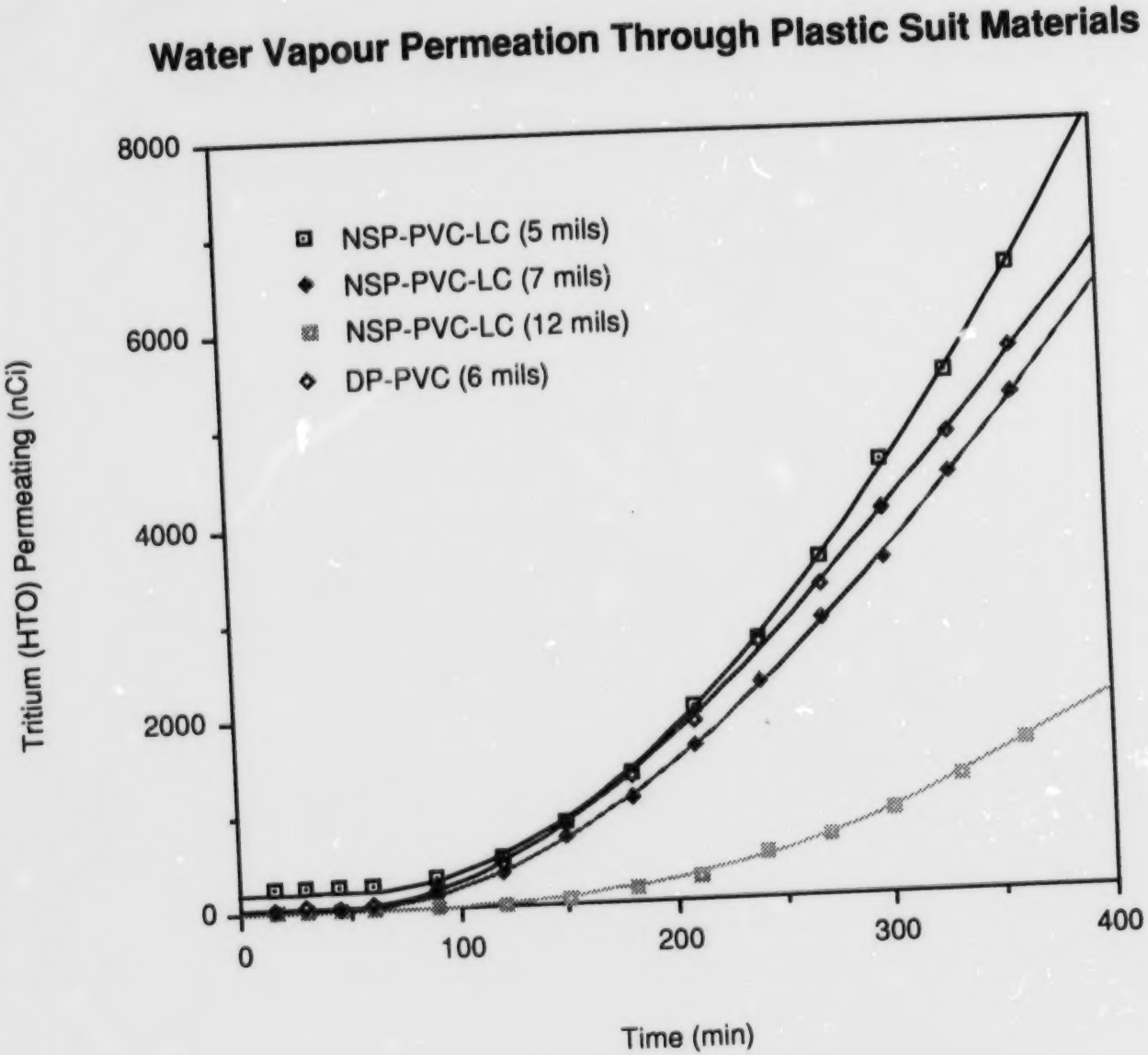

FIGURE 1

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table4567.gph(b)

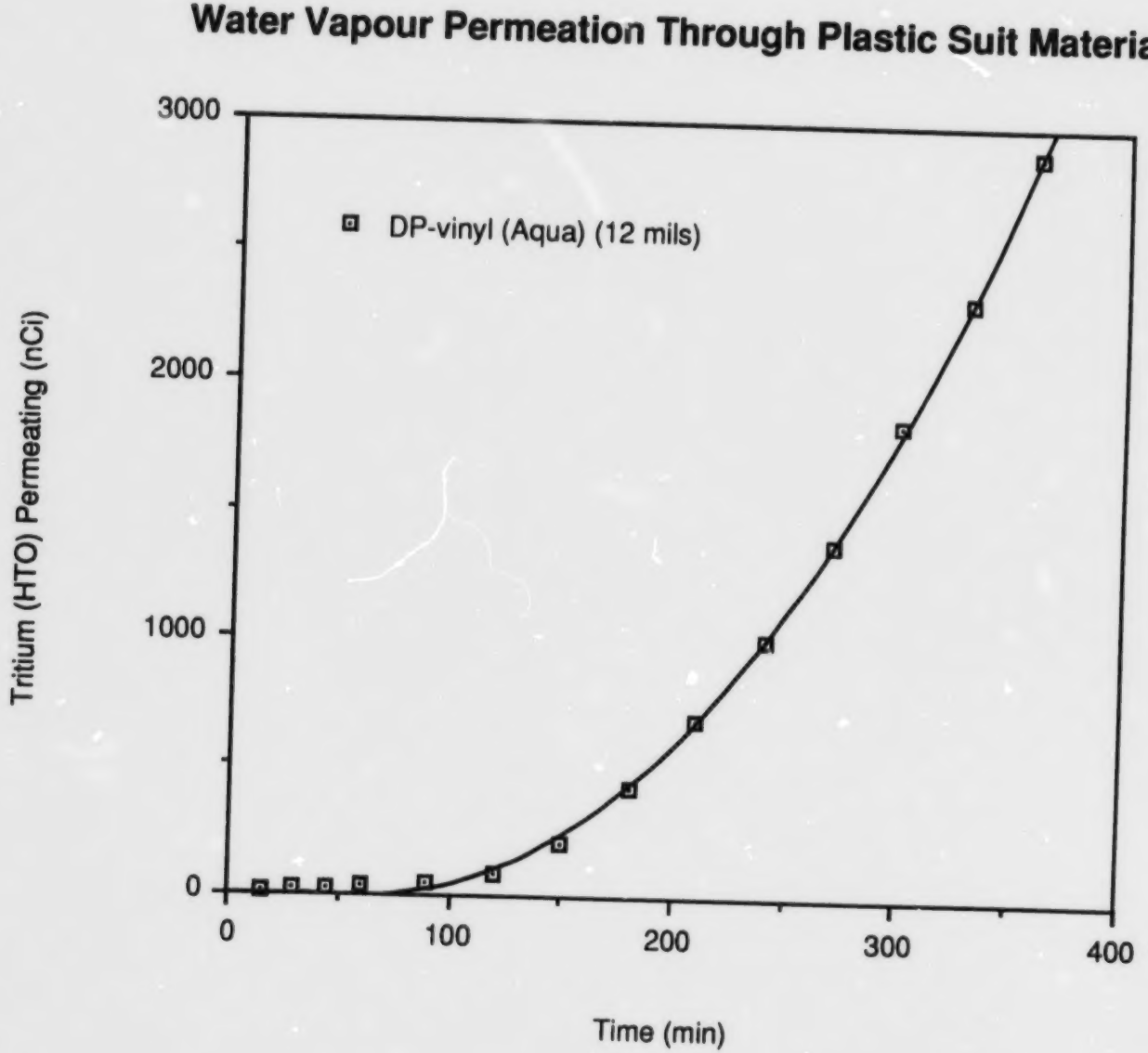

table8.gph(b)

FIGURE 2

Water Vapour Permeation Through Plastic Suit Materials

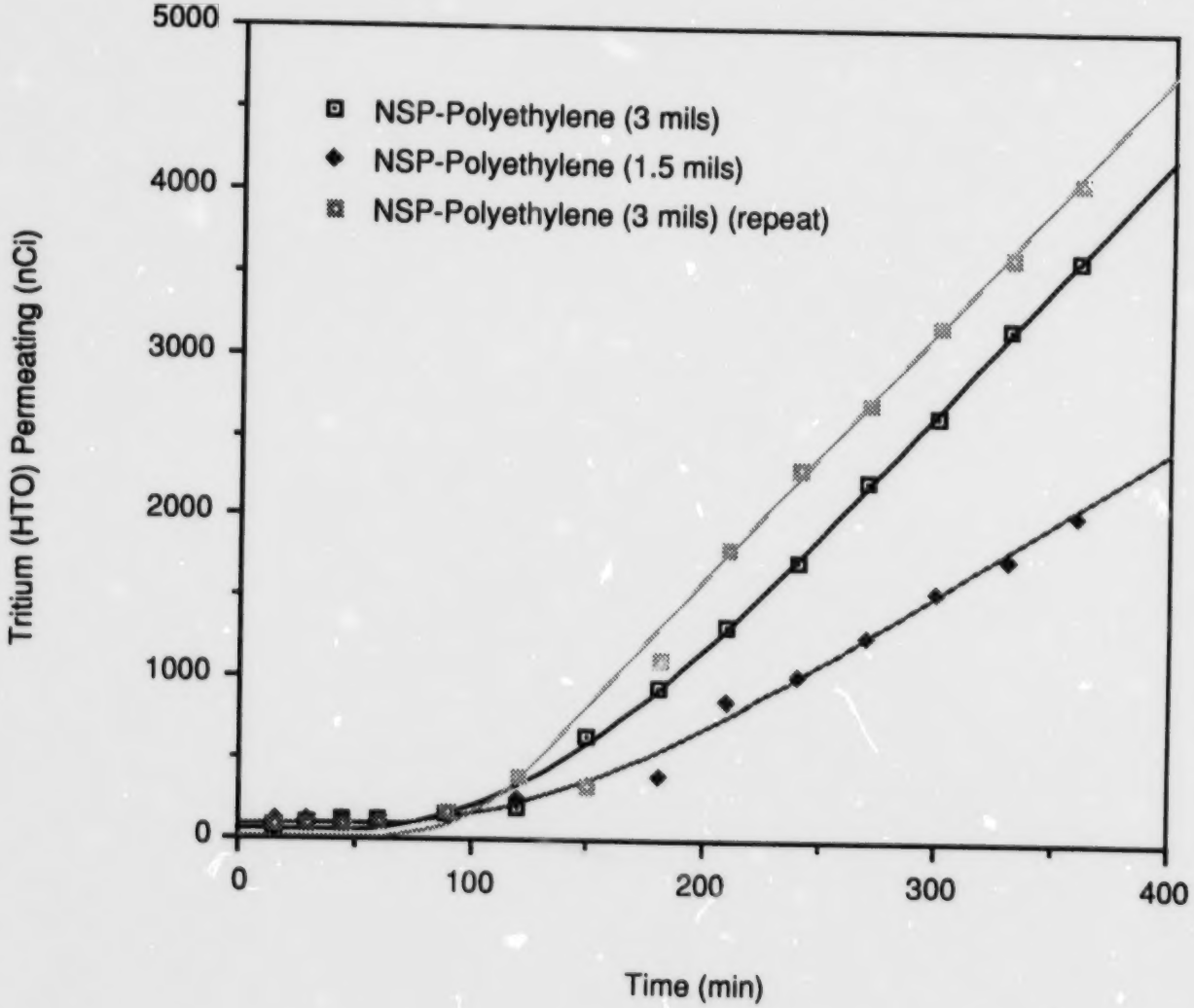

FIGURE 3

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table91012.gph(b)

Water Vapour Permeation Through Plastic Suit Materials

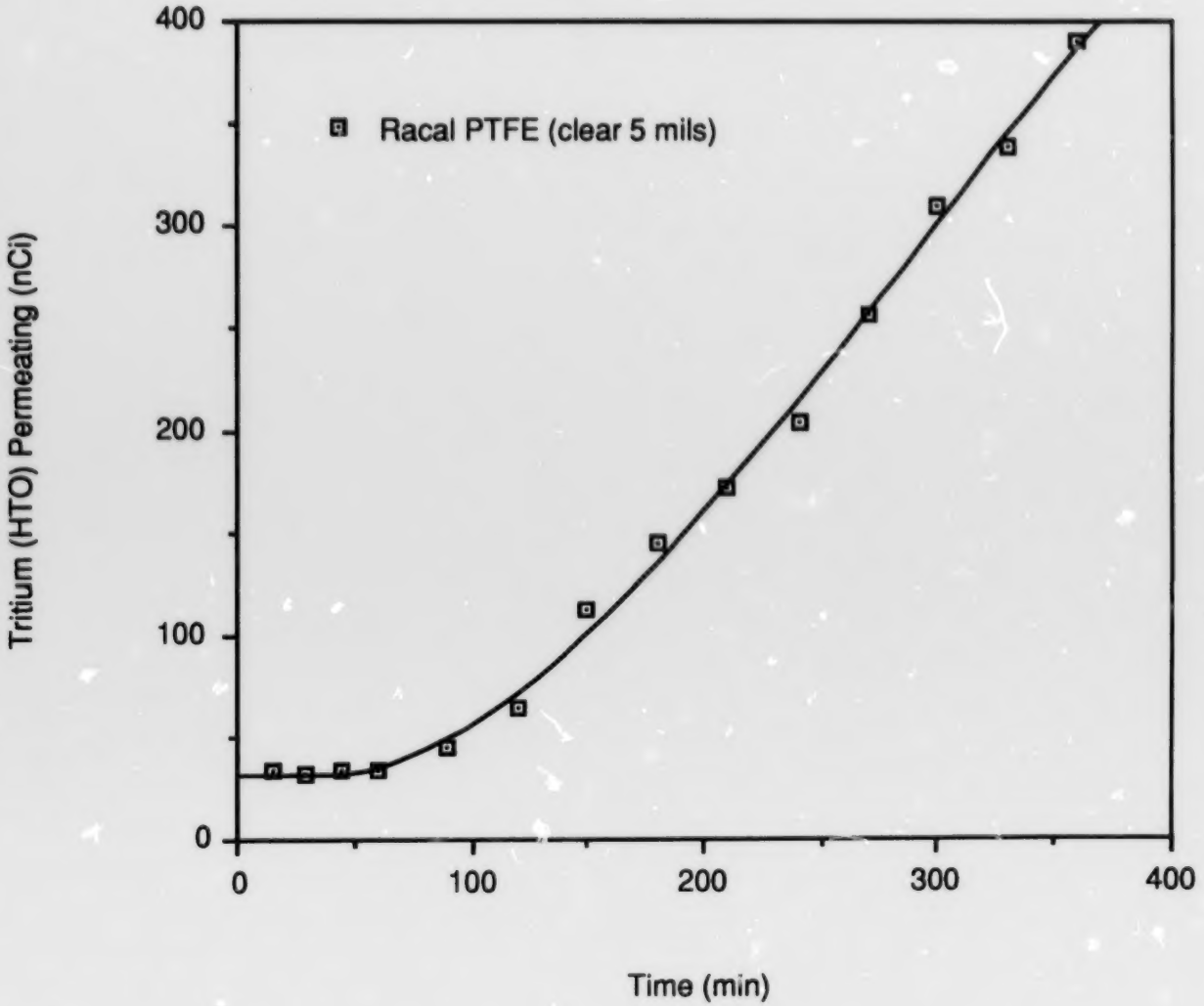

FIGURE 4

table11.gph(b)

Water Vapour Permeation Through Plastic Suit Materials

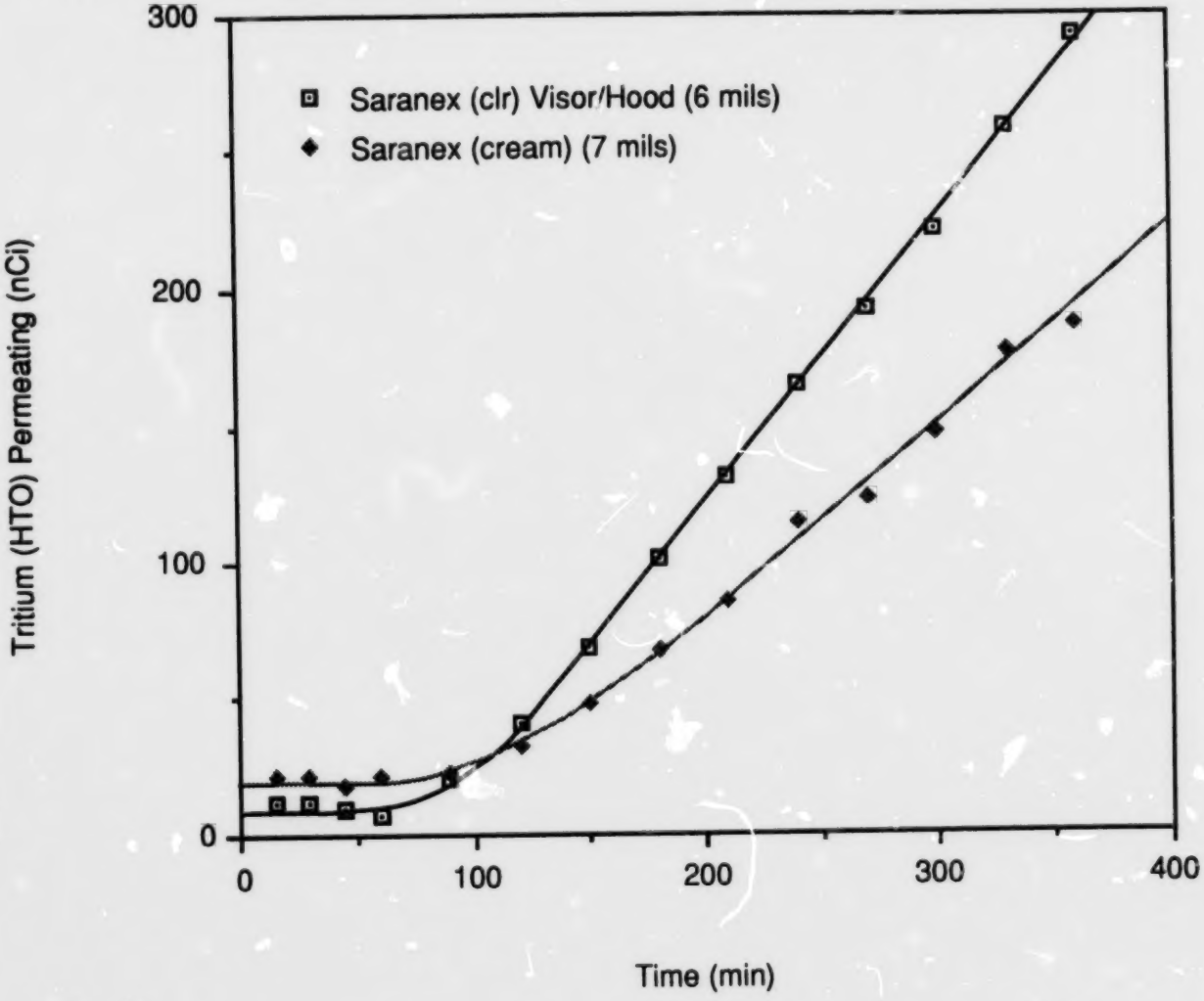

FIGURE 5

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table1314.gph(b)

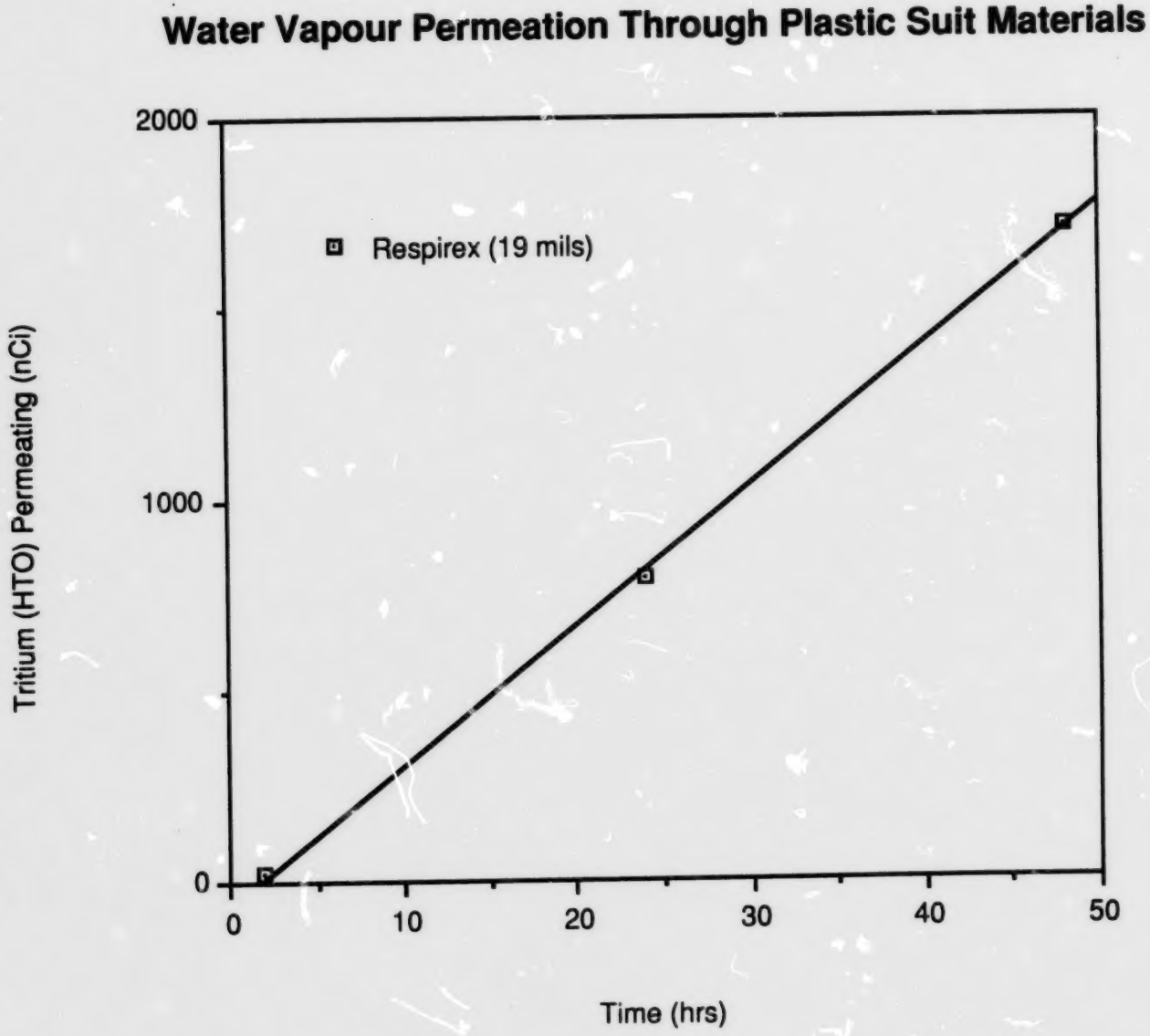

FIGURE 6

table15.gph(b)

APPENDIX 2

Permeation Data Tables

TABLE A2.1

WATER VAPOUR PERMEATION THROUGH NSP PVC (LOW CHLORIDE 2%)

Nitrogen Flow Rate = 50mL/min
Temperature = 23.0oC
Membrane = NPS PVC
Thickness = 0.15mm (5 mil)
Area = 6.41 cm*2
Tritium Concn =10.13 mCi/mL (MODERATOR WATER)
delta P at 23.0oC = 2.107cmHg

TIME (MIN)	DPM IN 1mL WATER		VOLUME IN BUBBLER (cc)		CUMULATIVE RELEASE (nCi)		
	Cell 1	Cell 2	Cell 1	Cell 2	Cell 1	Cell 2	Average
0			198.0	198.0			
15	4641.0	995.0	197.0	197.0	415.6	89.1	252.3
30	5045.0	910.0	196.0	196.0	449.5	81.1	265.3
45	5094.0	915.0	195.0	195.0	451.5	81.1	266.3
60	4710.0	1056.0	194.0	194.0	415.3	93.1	254.2
90	4971.0	2327.0	193.0	193.0	436.1	204.1	320.1
120	5455.0	6394.0	192.0	192.0	476.1	558.0	517.0
150	6758.0	12893.0	191.0	191.0	586.7	1119.3	853.0
180	10690.0	20211.0	190.0	190.0	923.2	1745.5	1334.4
210	18189.0	28960.0	189.0	189.0	1562.6	2487.9	2025.3
240	26647.0	36300.0	188.0	188.0	2277.1	3102.0	2689.6
270	37694.0	45469.0	187.0	187.0	3204.0	3864.9	3534.4
300	52539.0	54564.0	186.0	186.0	4441.9	4613.1	4527.5
330	65820.0	63604.0	185.0	185.0	5534.9	5348.5	5441.7
360	81575.0	74256.0	184.0	184.0	6822.6	6210.5	6516.6
1410	504798.0	355491.0	183.0	183.0	41965.1	29570.4	35767.7

TABLE A2.2

WATER VAPOUR PERMEATION THROUGH NSP PVC (LOW CHLORIDE 2%)

Nitrogen Flow Rate = 50mL/min
Temperature = 23.1oC
Membrane = NPS PVC
Thickness = 0.18mm (7 mil)
Area = 6.41 cm*2
Tritium Concn = 10.13mCi/mL (MODERATOR WATER)
delta P at 23.1oC = 2.119cmHg

TIME (MIN)	DPM IN 1mL WATER		VOLUME IN BUBBLER (cc)		CUMULATIVE RELEASE (nCi)		
	Cell 1	Cell 2	Cell 1	Cell 2	Cell 1	Cell 2	Average
0			198.0	198.0			
15	435.0	288.0	197.0	197.0	39.0	25.8	32.4
30	429.0	285.0	196.0	196.0	38.2	25.4	31.8
45	430.0	301.0	195.0	195.0	38.1	26.7	32.4
60	458.0	331.0	194.0	194.0	40.4	29.2	34.8
90	1071.0	1839.0	193.0	193.0	94.0	161.3	127.6
120	2349.0	5780.0	192.0	192.0	205.0	504.4	354.7
150	5449.0	10567.0	191.0	191.0	473.1	917.4	695.2
180	9585.0	15414.0	190.0	190.0	827.8	1331.2	1079.5
210	15733.0	21757.0	189.0	189.0	1351.6	1869.1	1610.4
240	23992.0	28698.0	188.0	188.0	2050.2	2452.4	2251.3
270	32491.0	35543.0	187.0	187.0	2761.7	3021.2	2891.4
300	40323.0	42359.0	186.0	186.0	3409.1	3581.3	3495.2
330	52795.0	51137.0	185.0	185.0	4439.6	4300.2	4369.9
360	63460.0	60272.0	184.0	184.0	5307.6	5040.9	5174.2
1440	410547.0	336748.0	183.0	183.0	34150.0	28011.3	31080.7

TABLE A2.3

WATER VAPOUR PERMEATION THROUGH NSP PVC (LOW CHLORIDE 2%)

Nitrogen Flow Rate = 50mL/min
Temperature @ 0 time=16.9oC, @ 2h=23.0oC, @6h=23.8oC
Membrane = NPS PVC
Thickness = 0.23mm (12 mil)
Area = 6.41 cm*2
Tritium Concn = 10.13mCi/mL (MODERATOR WATER)
delta P at

TIME (MIN)	DPM IN 1mL WATER		VOLUME IN BUBBLER (cc)		CUMULATIVE RELEASE (nCi)		
	Cell 1	Cell 2	Cell 1	Cell 2	Cell 1	Cell 2	Average
0			198.0	198.0			
15	282.0	201.0	197.0	197.0	25.3	18.0	21.6
30	320.0	225.0	196.0	196.0	28.5	20.0	24.3
45	241.0	260.0	195.0	195.0	21.4	23.0	22.2
60	241.0	238.0	194.0	194.0	21.3	21.0	21.1
90	289.0	297.0	193.0	193.0	25.4	26.1	25.7
120	256.0	331.0	192.0	192.0	22.3	28.9	25.6
150	310.0	1379.0	191.0	191.0	26.9	119.7	73.3
180	613.0	3112.0	190.0	190.0	52.9	268.8	160.9
210	1204.0	4848.0	189.0	189.0	103.4	416.5	260.0
240	3079.0	8042.0	188.0	188.0	263.1	687.2	475.2
270	4804.0	10278.0	187.0	187.0	408.3	873.6	641.0
300	7968.0	13083.0	186.0	186.0	673.7	1106.1	889.9
330	11689.0	17249.0	185.0	185.0	982.9	1450.5	1216.7
360	16393.0	21220.0	184.0	184.0	1371.1	1774.8	1572.9
1440	301545.0	239356.0	183.0	183.0	25083.1	19910.1	22496.6

TABLE A2.4

WATER VAPOUR PERMEATION THROUGH DELTA PROTECTION PVC (YELLOW)

Nitrogen Flow Rate = 50mL/min
Temperature =23.5oC
Membrane = PVC
Thickness = 0.18mm (6 mil)
Area = 6.41 cm*2
Tritium Concn = 10.13mCi/mL (MODERATOR WATER)
delta P at 23.5oC = 2.171cmHg

TIME (MIN)	nCi IN 1mL WATER		VOLUME IN BUBBLER (cc)		CUMULATIVE RELEASE (nCi)		
	Cell 1	Cell 2	Cell 1	Cell 2	Cell 1	Cell 2	Average
0			198.0	198.0			
15	0.29	0.2	197.0	197.0	57.1	37.4	47.3
30	0.3	0.2	196.0	196.0	64.7	33.3	49.0
45	0.3	0.2	195.0	195.0	60.5	33.2	46.8
60	0.4	0.2	194.0	194.0	71.8	44.6	58.2
90	0.6	1.4	193.0	193.0	106.2	260.6	183.4
120	1.0	3.8	192.0	192.0	197.8	727.7	462.7
150	2.2	7.1	191.0	191.0	418.3	1346.6	882.4
180	3.9	10.1	190.0	190.0	742.9	1920.9	1331.9
210	6.3	13.4	189.0	189.0	1181.3	2538.3	1859.8
240	10.3	18.2	188.0	188.0	1942.0	3416.0	2679.0
270	13.6	21.1	187.0	187.0	2545.1	3936.4	3240.7
300	18.4	24.9	186.0	186.0	3416.8	4637.0	4026.9
330	22.9	29.0	185.0	185.0	4238.4	5355.8	4797.1
360	28.3	33.1	184.0	184.0	5201.7	6084.9	5643.3
1440	255.0	178.8	183.0	183.0	46670.5	32711.3	39690.9

TABLE A2.5

WATER VAPOUR PERMEATION THROUGH DELTA PROTECTION VINYL GLOVE (AQUA)

Nitrogen Flow Rate = 50mL/min
Temperature =23.0oC
Membrane = VINYL
Thickness CELL 1 = 0.56mm :CELL 2 = 0.51mm (12 mil)
Area = 6.41 cm*2
Tritium Concn = 10.13mCi/mL (MODERATOR WATER CALCULATED JAN.25,1990)
delta P at 23.0oC = 2.107cmHg

TIME (MIN)	nCi IN 1mL WATER		VOLUME IN BUBBLER (cc)		CUMULATIVE RELEASE (nCi)		
	Cell 1	Cell 2	Cell 1	Cell 2	Cell 1	Cell 2	Average
0			198.0	198.0			
15	0.09	0.1	197.0	197.0	17.7	13.8	15.8
30	0.2	0.1	196.0	196.0	37.2	13.7	25.5
45	0.2	0.1	195.0	195.0	41.0	9.8	25.4
60	0.3	0.1	194.0	194.0	56.3	13.6	34.9
90	0.4	0.1	193.0	193.0	79.1	13.5	46.3
120	0.6	0.2	192.0	192.0	117.1	40.3	78.7
150	0.9	1.4	191.0	191.0	162.4	257.9	210.1
180	1.3	3.2	190.0	190.0	237.5	598.5	418.0
210	1.8	5.5	189.0	189.0	338.3	1033.8	686.1
240	2.7	8.1	188.0	188.0	498.2	1513.4	1005.8
270	3.8	10.9	187.0	187.0	708.7	2045.8	1377.3
300	5.3	14.5	186.0	186.0	987.7	2691.4	1839.5
330	7.3	17.9	185.0	185.0	1341.3	3306.0	2323.6
360	9.7	21.8	184.0	184.0	1775.6	4005.1	2890.4
1440	134.3	165.0	183.0	183.0	24584.2	30189.5	27386.9

TABLE A2.6

WATER VAPOUR PERMEATION THROUGH NSP POLYETHYLENE (1.5mil)

Nitrogen Flow Rate = 50mL/min
Temperature =22.8oC
Membrane = POLYETHYLENE
Thickness = 0.05mm (1.5 mil)
Area = 6.41 cm*2
Tritium Concn = 10.13mCi/mL (MODERATOR WATER CALCULATED JAN.25,1990)
delta P at 22.8oC =2.082cmHg

TIME (MIN)	nCi IN 1mL WATER		VOLUME IN BUBBLER (cc)		CUMULATIVE RELEASE (nCi)		
	Cell 1	Cell 2	Cell 1	Cell 2	Cell 1	Cell 2	Average
0			198.0	198.0			
15	0.57	0.6	197.0	197.0	112.3	122.1	117.2
30	0.6	0.6	196.0	196.0	107.8	117.6	112.7
45	0.6	0.6	195.0	195.0	115.1	117.0	116.0
60	0.6	0.6	194.0	194.0	116.4	122.2	119.3
90	0.7	0.9	193.0	193.0	125.5	179.5	152.5
120	0.9	1.9	192.0	192.0	170.9	361.0	265.9
150	1.2	2.4	191.0	191.0	234.9	448.9	341.9
180	1.7	2.5	190.0	190.0	317.3	469.3	393.3
210	2.8	6.3	189.0	189.0	531.1	1194.5	862.8
240	3.5	7.5	188.0	188.0	652.4	1402.5	1027.4
270	4.6	9.0	187.0	187.0	858.3	1675.5	1266.9
300	5.9	10.8	186.0	186.0	1091.8	2001.4	1546.6
330	7.0	12.0	185.0	185.0	1289.5	2220.0	1754.7
360	8.3	13.8	184.0	184.0	1534.6	2535.5	2035.0
4320	208.8	231.8	183.0	183.0	38208.6	42419.4	40314.0

TABLE A2.7

WATER VAPOUR PERMEATION THROUGH NSP POLYETHYLENE (3 mil)

*NOTE THAT THICKNESS FOR THIS TEST IS LESS THAN THE INITIAL TEST(0.09mm)

Nitrogen Flow Rate = 50mL/min
Temperature =22.7oC
Membrane = POLYETHYLENE
Thickness = 0.05mm (3 mil) (THICKNESS CONFIRMED)
Area = 6.41 cm*2
Tritium Concn = 10.13mCi/mL (MODERATOR WATER CALCULATED JAN.25,1990)
delta P at 22.7oC =2.069cmHg

TIME (MIN)	nCi IN 1mL WATER		VOLUME IN BUBBLER (cc)		CUMULATIVE RELEASE (nCi)		
	Cell 1	Cell 2	Cell 1	Cell 2	Cell 1	Cell 2	Average
0			198.0	198.0			
15	0.56	0.4	197.0	197.0	110.3	82.7	96.5
30	0.6	0.5	196.0	196.0	115.6	92.1	103.9
45	0.6	0.5	195.0	195.0	117.0	91.7	104.3
60	0.7	0.5	194.0	194.0	128.0	100.9	114.5
90	0.9	1.1	193.0	193.0	173.7	206.5	190.1
120	1.5	2.7	192.0	192.0	288.0	510.7	399.4
150	2.5	1.0	191.0	191.0	469.9	196.7	333.3
180	3.8	8.2	190.0	190.0	712.5	1556.1	1134.3
210	5.3	13.9	189.0	189.0	1003.6	2627.1	1815.3
240	7.4	17.1	188.0	188.0	1393.1	3211.0	2302.1
270	9.4	19.7	187.0	187.0	1750.3	3678.3	2714.3
300	11.6	22.7	186.0	186.0	2153.9	4212.9	3183.4
330	13.9	25.1	185.0	185.0	2566.0	4650.9	3608.4
360	16.2	28.1	184.0	184.0	2979.0	5175.9	4077.4
1440	112.3	135.2	183.0	183.0	20545.4	24741.6	22643.5

TABLE A2.8

WATER VAPOUR PERMEATION THROUGH RACAL PTFE (CLEAR 5mil)

Nitrogen Flow Rate = 50mL/min
Temperature =23.8oC
Membrane = PTFE
Thickness =0.12mm (5mil)
Area = 6.41 cm*2
Tritium Concn = 10.13mCi/mL (MODERATOR WATER CALCULATED JAN.25,1990)
delta P at 23.8oC =2.211cmHg

TIME (MIN)	nCi IN 1mL WATER		VOLUME IN BUBBLER (cc)		CUMULATIVE RELEASE (nCi)		
	Cell 1	Cell 2	Cell 1	Cell 2	Cell 1	Cell 2	Average
0			198.0	198.0			
15	0.19	0.2	197.0	197.0	37.4	31.5	34.5
30	0.2	0.2	196.0	196.0	33.3	31.4	32.3
45	0.2	0.2	195.0	195.0	35.1	31.2	33.2
60	0.2	0.2	194.0	194.0	36.9	29.1	33.0
90	0.2	0.3	193.0	193.0	38.6	50.2	44.4
120	0.2	0.4	192.0	192.0	44.2	84.5	64.3
150	0.3	0.9	191.0	191.0	55.4	170.0	112.7
180	0.4	1.2	190.0	190.0	68.4	222.3	145.4
210	0.4	1.4	189.0	189.0	79.4	264.6	172.0
240	0.5	1.6	188.0	188.0	101.5	306.4	204.0
270	0.7	2.0	187.0	187.0	136.5	377.7	257.1
300	0.9	2.4	186.0	186.0	169.3	452.0	310.6
330	1.1	2.6	185.0	185.0	199.8	479.2	339.5
360	1.3	3.0	184.0	184.0	239.2	542.8	391.0
1440	10.8	13.1	183.0	183.0	1976.4	2399.1	2187.8

TABLE A2.9

WATER VAPOUR PERMEATION THROUGH SARANEX (CLEAR) VISOR/HOOD (6 mil)

CELL 1 VOLUME=2.3 mL CELL 2 VOLUME=2.0 mL

Nitrogen Flow Rate = 50mL/min
Temperature =23.2oC
Membrane = CPE/EVA/SARAN/EVA
Thickness = 0.17mm (6 mil)
Area = 6.41 cm*2
Tritium Concn = 22.15mCi/mL (MODERATOR WATER CALCULATED MAR.20,1990)
delta P at 23.2oC =2.132cmHg

TIME (MIN)	nCi IN 1mL WATER		VOLUME IN BUBBLER (cc)		CUMULATIVE RELEASE (nCi)		
	Cell 1	Cell 2	Cell 1	Cell 2	Cell 1	Cell 2	Average
0			199.0	199.0			
15	0.09	0.0	198.0	198.0	17.8	5.9	11.9
30	0.1	0.0	197.0	197.0	15.8	7.9	11.8
45	0.1	0.0	196.0	196.0	11.8	7.8	9.8
60	0.0	0.0	195.0	195.0	7.8	5.9	6.8
90	0.1	0.2	194.0	194.0	11.6	29.1	20.4
120	0.1	0.4	193.0	193.0	13.5	67.6	40.5
150	0.2	0.6	192.0	192.0	28.8	109.4	69.1
180	0.3	0.8	191.0	191.0	53.5	149.0	101.2
210	0.4	1.0	190.0	190.0	81.7	180.5	131.1
240	0.6	1.1	189.0	189.0	121.0	209.8	165.4
270	0.8	1.3	188.0	188.0	150.4	235.0	192.7
300	0.9	1.4	187.0	187.0	175.8	267.4	221.6
330	1.2	1.6	186.0	186.0	213.9	303.2	258.5
360	1.3	1.8	185.0	185.0	246.1	338.6	292.3
1440	12.4	11.6	184.0	184.0	2272.4	2139.9	2206.2

TABLE A2.10

WATER VAPOUR PERMEATION THROUGH SARANEX (CREAM) (7 mil)
* 2-4mil THICKNESSES HEAT SEALED
CELL 1 VOLUME=2.0 mL CELL 2 VOLUME=2.0 mL

Nitrogen Flow Rate = 50mL/min
Temperature =22.6oC
Membrane = CPE/EVA/SARAN/EVA
Thickness = 0.20mm (7 mil)
Area = 6.41 cm*2
Tritium Concn = 22.15mCi/mL (MODERATOR WATER CALCULATED MAR.20,1990)
delta P at 22.6oC =2.057cmHg

TIME (MIN)	nCi IN 1mL WATER		VOLUME IN BUBBLER (cc)		CUMULATIVE RELEASE (nCi)		
	Cell 1	Cell 2	Cell 1	Cell 2	Cell 1	Cell 2	Average
0			198.0	198.0			
15	0.12	0.1	197.0	197.0	23.6	19.7	21.7
30	0.1	0.1	196.0	196.0	25.5	17.6	21.6
45	0.1	0.1	195.0	195.0	19.5	15.6	17.6
60	0.1	0.1	194.0	194.0	21.3	21.3	21.3
90	0.1	0.1	193.0	193.0	21.2	25.1	23.2
120	0.2	0.2	192.0	192.0	28.8	36.5	32.6
150	0.2	0.3	191.0	191.0	38.2	59.2	48.7
180	0.2	0.5	190.0	190.0	45.6	89.3	67.5
210	0.3	0.6	189.0	189.0	60.5	111.5	86.0
240	0.4	0.8	188.0	188.0	82.7	146.6	114.7
270	0.5	0.8	187.0	187.0	87.9	157.1	122.5
300	0.6	1.0	186.0	186.0	109.7	184.1	146.9
330	0.8	1.1	185.0	185.0	142.5	210.9	176.7
360	0.8	1.2	184.0	184.0	149.0	224.5	186.8
1440	9.5	8.6	183.0	183.0	1734.8	1566.5	1650.7

TABLE A2.11

WATER VAPOUR PERMEATION THROUGH RESPIREX

CELL 1 VOLUME=2.3 mL CELL 2 VOLUME=2.3 mL

Nitrogen Flow Rate = 50mL/min
Temperature =23.5oC
Membrane = Viton/Butyl Rubber
Thickness = 0.49mm (19 mil)
Area = 6.41 cm*2
Tritium Concn = 22.15mCi/mL (MODERATOR WATER CALCULATED MAR.20,1990)
delta P at 23.5oC =cmHg

TIME (HOURS)	nCi IN 1mL WATER		VOLUME IN BUBBLER (cc)		CUMULATIVE RELEASE (nCi)		
	Cell 1	Cell 2	Cell 1	Cell 2	Cell 1	Cell 2	Average
0	0.4	0.2	200.0	200.0	0.0	0.0	0.0
2	0.5	0.3	198.0	198.0	33.7	13.9	23.8
24	4.3	4.5	196.0	196.0	766.4	831.0	798.7
48	8.6	9.7	194.0	194.0	1592.7	1827.5	1710.1
120	40.4	41.7	192.0	192.0	7681.9	7954.6	7818.2
144	61.0	62.0	190.0	190.0	11514.0	11738.2	11626.1
168	86.1	86.9	188.0	188.0	16124.8	16282.7	16203.7
283	216.4	226.3	186.0	186.0	40182.5	42045.3	41113.9
384	346.8	372.3	184.0	184.0	63741.3	68453.5	66097.4